

THE IMPORTANCE OF THE INITIAL GEOMETRY IN HEAVY ION COLLISIONS

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Elliptic flow, elliptic flow fluctuations and fluctuations in the initial geometry point to a description of nuclear collisions that is driven by the initial geometry, a quantity which appears to be imprinted from the instant of the collision. In these proceedings, recent results from the PHOBOS collaboration are discussed in the context of the importance of the collision geometry.

1 Introduction

Since the start of the RHIC program the measurement of particle azimuthal anisotropy, or flow, has been considered as one of the most important probes of nuclear collisions. Elliptic flow, in particular, is an important property of particle production as it is sensitive to the early stages

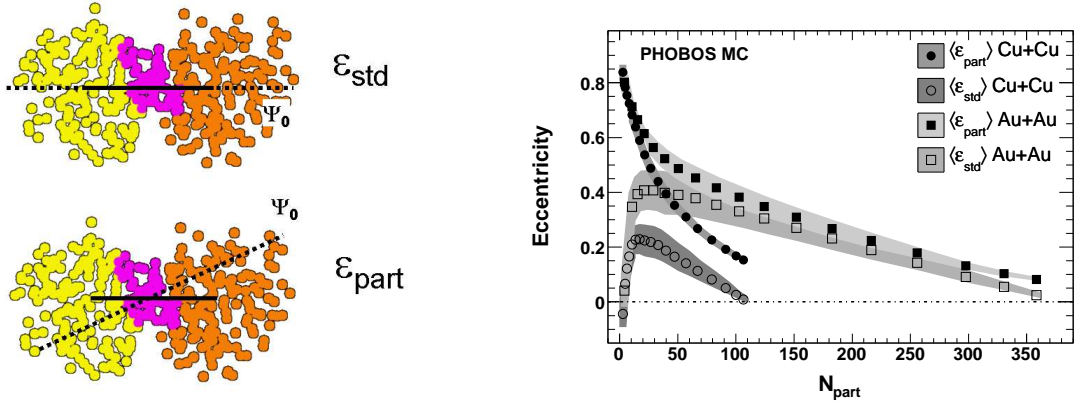


Figure 1: The left panel visualizes the two approaches to calculating eccentricity. The purple region (at center) in each collision illustrates the interacting nucleons. The orange and yellow nucleons (away from collision zone) are assumed not to directly influence the eccentricity. The solid (dashed) line represents the collision (participant) reaction plane. The lower part shows that the assumed reaction plane is rotated into the plane which maximizes the eccentricity, i.e. aligned along the semi-minor axis of the participant region. The right panel shows the difference of these two approaches for both Au+Au and Cu+Cu collisions. Cu+Cu collisions show a significant difference in the calculated eccentricity, whilst the discrepancy is less for Au+Au collisions.

of the collision and thus its study affords unique insights into the properties of the hot, dense matter that is produced in these collisions. At the root of this measurement lies a connection to the initial overlap geometry of the colliding nuclei, in particular the eccentricity of the initial overlap region of nucleons, which can be discussed as an averaged or event-by-event property of the system. The PHOBOS experiment has measured the elliptic flow for Au+Au and Cu+Cu collisions from $\sqrt{s_{NN}} = 19.6$ to 200 GeV, versus centrality and transverse momentum. For 200 GeV Au+Au collisions, a new analysis of the fluctuations in the magnitude of elliptic flow have revealed a startling agreement with a simple geometrical model of nuclear collisions.

2 Initial Collision Geometry

The collision geometry has always played an important role in heavy-ion collision analysis. The most simplistic definitions of centrality, derived from a Glauber model¹, and consequently the number of nucleons, N_{part} , expected to have participated in the collision is fundamental to this area of high-energy physics. As well as N_{part} , additional information can be gained from this model, including the spatial anisotropy of the collection of participating nucleons, or eccentricity (ϵ). This anisotropy leads to the observed elliptic flow signal in data, discussed in the next sections. There are several methods for calculating ϵ , two of which are illustrated in Fig. 1. On the left, a schematic depiction of the “standard” (top, ϵ_{std}) and “participant” (bottom, ϵ_{part}) methods are shown. The former assumes that the collection of participating nucleons is oriented such that the semi-minor axis is aligned along the *reaction plane* - through the centers of the original colliding nuclei. As one can see, this is not always the case and may thus result in a reduced eccentricity. For the participant method, the semi-minor axis is allowed to rotate, such that the eccentricity is maximized. Eqn. 1 is a mathematical representation of the eccentricity for both methods.

$$\epsilon_{std} = \frac{\sigma_y^2 - \sigma_x^2}{\sigma_y^2 + \sigma_x^2} \quad \epsilon_{part} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2} \quad (1)$$

The difference in mean eccentricity between these two methods can be seen on the right panel of Fig. 1. For central Au+Au collisions little difference is observed between the two. For

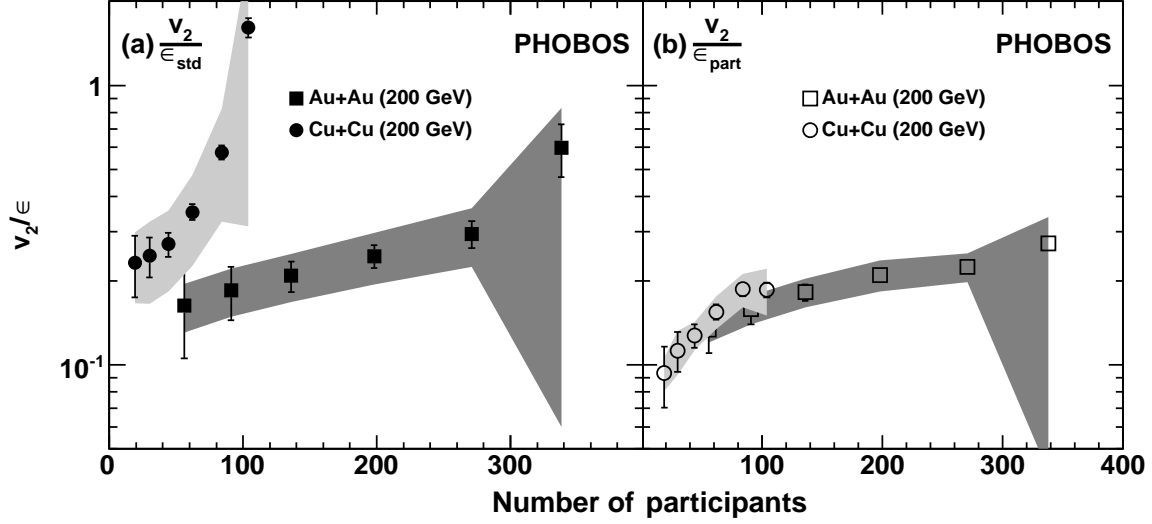


Figure 2: The elliptic flow, v_2 , scaled by the eccentricity from a Glauber model calculation for the (a) standard and (b) participant approaches. Data are for Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200\text{ GeV}$. Shaded bands (error bars) represent the systematic (statistical) uncertainty.

more peripheral Au+Au or Cu+Cu collisions, large differences are seen, due primarily to the finite number of participating nucleon in such collisions. This difference in the magnitude of the eccentricity calculated using both methods from the model is observed in the elliptic flow data.

3 Elliptic Flow

Measurements of the elliptic flow, \check{v}_2 , from PHOBOS are made over a broad range of pseudorapidity, centrality and energy. Generic features of particle production are found for both the Au+Au and Cu+Cu systems. At midrapidity, for similar centrality selections, the magnitude of \check{v}_2 increases from the lowest collision energy of $\sqrt{s_{NN}} = 19.6\text{ GeV}$ up to 200 GeV ². The magnitude of the \check{v}_2 diminishes as the pseudorapidity increases (for more forward particles) and is found to have a roughly triangular shape². The coupling of the collision energy and pseudorapidity dependences result in the \check{v}_2 signal exhibiting an extended longitudinal scaling behaviour² whereby the magnitude of \check{v}_2 is the same at the same pseudorapidity relative to beam rapidity (i.e. in the rest frame of one of the incoming nuclei).

The centrality dependence of \check{v}_2 shows the first clear dependence of the particle distributions following the underlying geometrical shape³. For central Au+Au collisions with an almost full overlap (small impact parameter) both the \check{v}_2 and the eccentricity are found to be small, see Fig. 1. As the impact parameter increases, collisions assume an almond shape, and \check{v}_2 and the eccentricity both increase.

For Au+Au collisions, it is found that \check{v}_2 scales reasonably with the standard eccentricity, ϵ_{std} , whereas the Cu+Cu data strongly violate this approximate scaling, see Fig. 2a. Considering the alternate technique, the participant eccentricity, yields a unification of the two data samples, Fig. 2b.

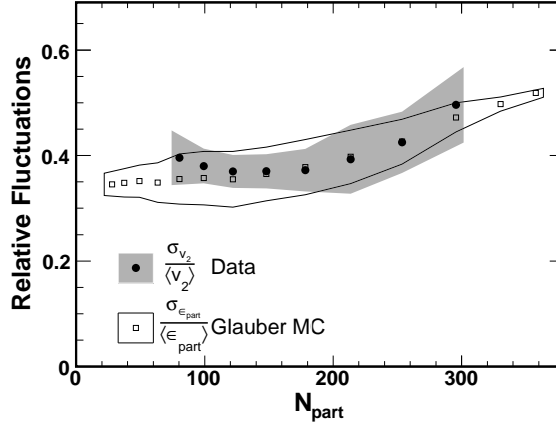


Figure 3: Comparison of the elliptic flow fluctuations, σ_{v_2} , to fluctuations in the initial geometry (eccentricity) from a Glauber model. Data are for Au+Au collisions at $\sqrt{s_{NN}} = 200\text{GeV}$.

4 Elliptic Flow Fluctuations

The collision species dependence of the integrated elliptic flow signal is found to be strongly dependent on the collision geometry, and to its precise definition. Specifically, the fluctuations in the nucleon positions on an event-by-event basis appears to drive the final $\tilde{2}$ signal. If such fluctuations influence the averaged signal, then this should be a measurable quantity in itself. One of the latest results from the PHOBOS collaboration concentrates on measuring these elliptic flow fluctuations. The method utilizes the whole pseudorapidity coverage of the PHOBOS detector to measure the $\tilde{2}$ signal on an event-by-event basis, assuming the shape is either a triangle or a trapeziod. Details of the analysis method can be found in Ref. ⁴.

The elliptic flow fluctuations, expressed as σ_{v_2}/v_2 , are shown in Fig. 3. The fluctuations are found to be significant for all centrality classes studied, with a peak close to 50% relative fluctuations. Fluctuations in the eccentricity from the Glauber model calculations are also found to be significant, with the magnitude in remarkable agreement with the $\tilde{2}$ fluctuations. Such an agreement hints that the detailed initial geometrical configuration is imprinted on the final distribution of particles.

5 Summary

The initial geometry in nuclear collisions plays an important role in particle production at RHIC. The detailed eccentricity, calculated from the positions of the interacting nucleons in a Glauber model, has been shown to unify elliptic flow data from Au+Au and Cu+Cu collisions. The magnitude of elliptic flow fluctuations are measured and are found to be large for all centralities. The level of these fluctuations is strikingly similar to those from the eccentricity calculations, indicating that the initial geometry is imprinted on the final particle distributions.

Acknowledgments

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